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Improved Sustainability through Treatment of High Rheology due to Excessive Low Gravity Solids: A Case Study and Field Trial

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Abstract

Exploration & Production (E&P) and oilfield service companies are under increasing pressure to raise the sustainability of all aspects of oil and gas operations. Repeated recycling of invert emulsion drilling fluids (IEF) is a key to this initiative. However, it results in buildup of low gravity drill solids (LGS) that conventional solids control has difficulty removing due to its fine particle size. High LGS in IEFs results in increased viscosity, which is difficult to treat with conventional industry additives. The typical remediation to combat this rheological dilemma is dilution of the IEF, an option plagued with environmental, logistical, operational efficiency, and cost issues. With a focus on performance and reducing environmental impact, a bio-based novel wetting agent (NWA) was developed to effectively treat this challenge thereby increasing the longevity of the usable life of the IEF and delaying associated disposal.

The field use of the NWA was investigated both at the rig site and for restoring rheological parameters of recycled IEFs at the mud plant. The NWA was compared to treatment with conventional industry additives in similar IEFs and evaluated through rheological parameters.

Treatment of IEFs with industry standard additives exhibited a minimal reduction in rheology after treatment, however, reconditioning with the NWA significantly reduced and maintained consistent rheology. The reduction in rheology resulted in improved sustainability observed through reduced chemical use, minimized dilution, and prolonged IEF inventory.

Introduction

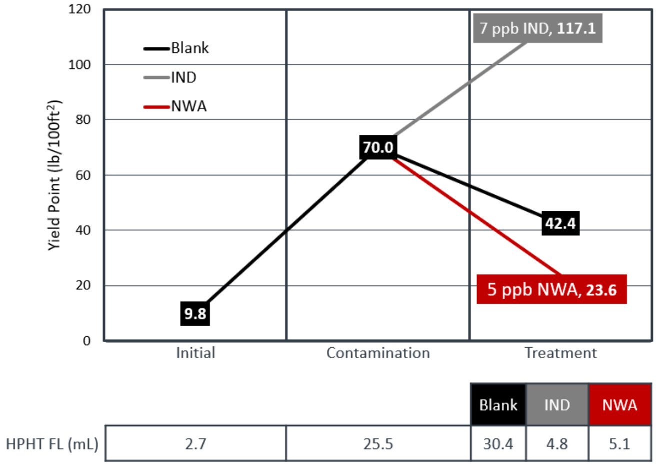
By the end of 2022, the world economy was shaken by the global pandemic and tragic conflict in Eastern Europe leaving the energy transition in disarray with a more short-term reliance on fossil fuels (McKinsey & Company 2022). The market already demanded E&P companies work toward a more sustainable future with Net Zero targets insisting the oil and gas sector drastically reduce emissions by 2050 by up to 90% (International Energy Agency 2021). Oilfield service providers are taking this opportunity to adapt and achieve operational and cost efficiency, reduce their carbon footprint, and actively introduce clean energy developments (Bansai, et al. 2022). Efficiency and sustainability have been proactively driven by incorporating bio-based chemistries, or renewable resources, with optimal performance (Smith, et al. 2022). This paper describes one such chemistry, a bio-based novel wetting agent (NWA). The NWA is proposed here as a solution for yet another push for efficiency and sustainability, recycling IEFs.

Continued recycling of drilling fluids results in a buildup of LGS that conventional solids control has difficulty removing due to its fine particle size. These recycled IEFs exhibit high viscosity that can lead to a breakdown of the emulsion and ultimately cause costly issues such as formation damage, surge and swab pressure buildup, and stuck pipe (Robinson 2006). The sustainability of IEFs reaches a breaking point with continued recycling and excessive LGS. Most standard wetting agents have a threshold concentration at which their restorative effect is reversed, and the fluid becomes too thick. At this point in the lifecycle, the standard practice is dilution of the IEF with new fluid. Though dilution reconditions the drilling fluid, it negatively impacts efficiency and sustainability with increased IEF inventory, storage space, subsequent transport to the field, and ultimately increased IEF disposal. A chemical treatment, such as the bio-based NWA, to combat this rheological dilemma could improve efficiency and reduce the environmental impact.

To treat high rheology of IEFs with increased concentrations of LGS, the NWA was developed (Hernandez, et al. 2022). The authors developed a lab procedure (coined the lifecycle procedure) that simulates the recycling IEFs in the field. The procedure included an initial stage with a typical North American land IEF, a contamination stage with 20% v/v LGS added and sheared to reduce particle size, and a treatment stage where the NWA was compared to industry-standard treatments. This procedure demonstrated the field issue where industry standard treatments exhibited elevated rheology after treatment. Hernandez et al presented an improved solution with the use of the NWA that significantly reduced and maintained consistent rheology with improved emulsion stability and reduced fluid loss as shown in Figure 1 (2022).

In collaboration with our co-authors, this work presents the NWA application in the field and further evaluates the impact of the NWA on the efficiency and sustainability of the drilling fluid.

Figure 1: Lifecycle Performance a Blank, Industry Standard (IND), and NWA (Hernandez, et al. 2022)



The NWA was shown to successfully deliver:

- Significant decrease in overall mud rheology when highly contaminated with LGS
- Versatility in both diesel and mineral oil-based drilling systems
- Use at both the rig site and at the mud plant
- Restoration of recycled muds with improved efficiency and sustainability
- Prolonged drilling fluid functional life

Performance Methods

The rheology of the fluid was characterized using the Bingham plastic model in terms of plastic viscosity (PV), yield point (YP), and gel strength (GS). The PV represents the viscosity of fluid when extrapolated to an infinite shear rate and is often used to describe the physical resistance of a mud, while the YP is obtained by extrapolating to a shear rate of zero and is associated with the chemical resistance caused by interparticle forces (Chillingarian, et al. 1983). Both PV and YP were calculated using the 300 rpm and 600 rpm shear rate readings as given in Equations 1 and 2.

$$PV = 600\,rpm\,Reading - 300\,rpm\,Reading \qquad \textit{(1)}$$

$$YP = 300\,rpm\,Reading - PV \qquad \textit{(2)}$$

Gel strength was measured as the inflection point at 3 rpm after keeping the fluid static for 10 seconds, 10 minutes, and/or 30 minutes. All measurements were performed at 120˚F.

Field Treatment of Fluids at Rig Site

As of January 2023, the NWA was used successfully at multiple rig sites. In this paper, a case history is presented in coordination with our co-authors on a well in the US northeast. The NWA has been used at rig sites in primarily diesel based IEFs as the one described in Table 1.

Table 1: Standard Formulation of Field Drilling Fluid

Component	ppb
Diesel	As needed
Lime	7.5
Organoclay	4.0
Primary Emulsifier	2.0
Secondary Emulsifier	8.0
Wetting Agent	1.0
25% $CaCl_2$ Brine	As needed
Barite	As needed
FLA	5.0
NWA for recondition	**1.0 – 2.0**

The NWA was dosed at approximately 1-2 ppb for this 11.5 ppg diesel IEF at increasing depths. As the v/v LGS increased from approximately 8% to 10.5% the NWA helped maintain rheological parameters. The overall stable and consistent rheology with increasing LGS can be seen in Table 2.

Table 2: Field Data of the Use of NWA

Depth (ft)	8000	10300	13000	16598
Activity	8.5" Open Hole	8.5" Open Hole	8.5" Open Hole	Run 5.5" Casing
Mud Wt (ppg)	11.5	11.5	11.5	11.8
600 rpm (DR)	49	48	52	52
300 rpm (DR)	29	29	31	31
200 rpm (DR)	21	21	22	21
100 rpm (DR)	14	15	16	14
6 rpm (DR)	9	9	9	9
3 rpm (DR)	8	8	8	8
PV (cP)	20	19	21	21
YP ($lb/100ft^2$)	9	10	10	10
10s Gel ($lb/100ft^2$)	7	8	10	10
10m Gel ($lb/100ft^2$)	12	12	15	16
30m Gel ($lb/100ft^2$)	14	15	19	19
Oil/Water Ratio	79/21	80/20	81/19	80/20
% LGS (v/v)	8.08	8.59	9.52	10.5

Reconditioning Fluids at Mud Plant

The experimental evaluation of the restoration of recycled IEFs consisted of comparing the NWA treatment of an IEF returned for reconditioning with standard reconditioning procedures. The NWA-treated, mineral oil-based IEF was leased by our co-authors and had been used to drill in the Utica shale play.

Field Performance

A customer of our co-authors came to them with 450 bbls of a leased mineral oil-based field mud loaded with 14% v/v LGS to be reconditioned and asking for more field ready mud. The leased IEF was no longer treatable in the field and deemed unusable. With an atypically high rheological profile and high LGS, the leased IEF presented a prime opportunity to test out the NWA. After a small-scale trial, the 450 bbls of IEF were treated with a 275-gal tote or 4.67 ppb of the NWA at the mud plant. The rheological parameters from pre- and post-treatment with the NWA, with no additional solids removal or dilution, can be found in Table 3.

Table 3: Rheological Parameters of IEF Pre and Post Treatment

Rheological Parameters	Pre- Treatment	Post-Treatment with 4-5 ppb NWA
600 rpm (DR)	104	84
300 rpm (DR)	68	50
200 rpm (DR)	53	38
100 rpm (DR)	39	26
6 rpm (DR)	19	10
3 rpm (DR)	18	9
PV (cP)	36	34
YP (lb/100ft^2)	**32**	**16**
10s Gel (lb/100ft^2)	**28**	**14**
10m Gel (lb/100ft^2)	33	21
30m Gel (lb/100ft^2)	38	25

A 50% reduction in YP and gel strengths were delivered with the NWA. The NWA-restored IEF was immediately sent back to the field by our co-authors for further drilling of O&G wells with no further complaints on the performance of the IEF treated with NWA.

According to our co-authors and their history reconditioning IEFs of this nature, the returned mud would have had to be diluted by 30 – 40% with fresh mud to achieve a similar reconditioning effect to that of the NWA. In other words, for each 100 bbl of mud, 30 – 40 bbl of the dilution is required. Our co-authors' standard reconditioning protocol for dilution of the 450 bbls of returned leased mud can be found in comparison to the treatment with the NWA in Table 4.

Table 4: Dilution of 450 bbls of Returned Field Mud

Component	NWA	30% Dilution	40% Dilution
NWA (gal)	275	0	0
Mineral Oil (bbl)	0	95	125
Lime (sacks)	0	20	27
Primary Emulsifier (gal)	0	135	180
Wetting Agent (gal)	0	135	180
Water (bbl)	0	40	55
$CaCl_2$ (sacks)	0	52	70

Efficiency & Sustainability Impact

The impact for the reconditioning example analyzed treatment with the NWA versus our co-author's standard reconditioning protocol for dilution. There is a clear efficiency gain with the use of the NWA in minimized dilution and inventory by eliminating the production of 30 – 40% overall more IEF. With dilution increasing the total volume of mud from 455 bbls to 585 – 630 bbls, dilution requires increased storage space as well as an increase in eventual disposal costs. Furthermore, dilution results in 95 – 98% increase in the usage of base oil and other additives, giving treatment with the NWA an obvious cost advantage over dilution. From a sustainability point of view, each additional component requires a certain amount of energy to make and has its own emissions factor. Therefore, the 95-98% reduction in additives with the treatment of the NWA adds to the improvement of the overall sustainability picture.

Our co-authors reported a difference in time to recondition the IEFs between the two methods. The treatment with NWA was quickly achieved within a 1 hour timeframe, where dilution would have required more additions and may have taken up to 4 hours. **This approximate 75% reduction in equipment time is directly correlated to reductions in energy use and CO_2 emissions.**

Another key sustainability metric analyzed was CO_2 emissions due to increased transport of higher volumes resulting from dilution. Following this example, 450 bbls of IEF would have been diluted by 30 – 40% equaling an increased total of 585 – 630 bbls of IEF. The following factors are key to calculating CO_2 emissions:

- 100 miles: approximate distance from mud plant to field, based on our co-authors' operations
- 5.94 MPG: average fuel efficiency of diesel tanker truck in the region (Geotab 2016)
- 10,180 g CO_2/gal of diesel: average emissions per gal of diesel (EPA Office of Transportation and Air Quality 2018)
- 5000 gal/tanker truck: standard value
- 42 gal/bbl: standard value
- 454 g/lb: standard value

The reduction of greenhouse gas in the form of CO_2 emissions as a result of the use of the NWA was calculated using Equations 3 – 7 below:

$$Trucks\ (\#) = IEF\ (bbls) * \frac{42\ gal}{bbl} * \frac{truck}{5{,}000\ gal} \quad (3)$$

$$Miles\ (total) = Trucks(\#) * 100\ miles \quad (4)$$

$$Diesel\ (gal) = Miles\ (total) * \frac{gal}{5.94\ miles} \quad (5)$$

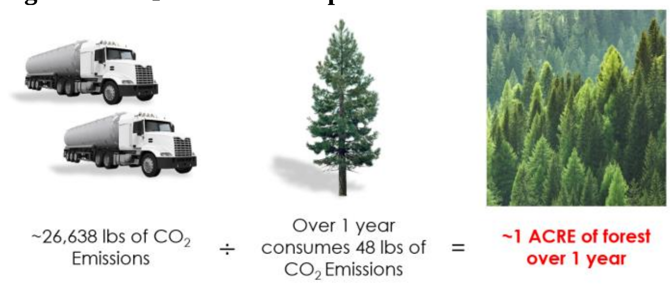
$$Emissions\ (g\ of\ CO_2) = Diesel\ (gal) * \frac{10{,}180\ g\ CO_2}{gal} \quad (6)$$

$$Emissions\ (lbs\ of\ CO_2) = Emissions\ (g\ of\ CO_2) * \frac{lb}{454\ g} \quad (7)$$

Based on the above calculations the 450 bbls of returned IEF treated with NWA would require 4 trucks, while if diluted it would have required 6 trucks. **This amounts to a 33% reduction in transport, which translates by the calculations above to an emission reduction of approximately 26,638 lbs CO_2.** To put this in perspective, over a year a mature tree consumes 48 lbs of CO_2 (Vandermel 2020). To consume the emissions from the 2 tanker trucks, it would require the annual

CO_2 consumption of 555 trees or around 1 acre forest of trees each planted 10 ft apart (Self and Ezell 2022) (Figure 2).

Figure 2: CO_2 Emission Perspective



In summary, treatment of high rheology in IEFs due to LGS with the bio-based NWA positively impacts efficiency and sustainability over the standard alternative of dilution. Efficiency and cost savings are achieved through minimizing dilution, base oil and additives, time to recondition, storage, and transport of IEFs. These efficiencies are directly tied to sustainability in the 95-98% reduction in additive usage, 75% reduction in energy used to recondition the NWA treated IEF, and the resulting 33% reduction in transport. The 26,638 lbs of CO_2 emissions calculated from reduced transport is just a piece of the overall efficiency and sustainability picture of the NWA reconditioned IEF.

Conclusions

- The NWA was used successfully at a rig site to maintain stable and consistent rheology.
- A 5 ppb dose of the NWA was able to recondition an unusable field mud with 14% LGS and high rheology and return it to the field thus extending the life of IEF.
- Restoration with the NWA improved both efficiency and sustainability by reducing the total volume of mud produced by 30 – 40%, base oil and additives by 95-98%, time in the mud plant by 75%, and transport by 33%. A piece of the overall sustainability picture was calculated as an example of the emissions saved with NWA treatment resulting in reductions in emissions of approximately 26,638 lbs CO_2 due to transport.

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Nomenclature

10' Gel = *10 Minute Gel Strength*
10" Gel = *10 Second Gel Strength*
30' Gel = *30 Minute Gel Strength*
bbl = *Barrel*
$CaCl_2$ = *Calcium Chloride*
CO_2 = *Carbon Dioxide*
cP = *Centipoise*
DR = *Dial Reading*
°F = *Degree Fahrenheit*
ES = *Electrical Stability in V*
E&P = *Exploration & Production*
ft = *Foot*
g = *Grams*
gal = *Gallons*
IEF = *Invert Emulsion Fluid*
IND = *Industry Standard Treatment*
lb = *Pound*
LGS = *Low Gravity Solids*
min = *Minute*
MPG = *Miles Per Gallon*
NWA = *Novel Wetting Agent*
O&G =*Oil & Gas*
% = *Percent*
PV = *Plastic Viscosity in Bingham Plastic Model in cP*
ppb = *Pound per Barrel*
ppg = *Pound per Gallon*
rpm = *Revolutions per Minute*
SS = *Shear Stress (Dial Reading)*
US = *United States of America*
V = *Volts*
v/v = *Volume to Volume ratio percentage*
Wt = *Weight*
YP = *Yield Point in Bingham Plastic Model in* $lb/100ft^2$

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